Journal of the Royal Society of Western Australia, Vol. 69, Part 1, 1986, p. 7-11.

Salmonella infections and animal condition in the mainland and Bald Island populations of the quokka (*Setonix brachyurus:* Marsupialia)

by R. P. Hart, [1]S. D. Bradshaw [1,3] and J. B. Iveson [2]

[1] Department of Zoology, University of Western Australia, Nedlands, 6009, Australia, and [2] Public Health and Enteric Diseases Unit, State Health Laboratory Services, Queen Elizabeth II Medical Centre, Nedlands, Western Australia 6009.

[3]Corresponding author.

Manuscript received 18 March 1986; accepted 17 June 1986

Abstract

The cause and significance of *Salmonella* infections in the quokka have been studied previously on Rottnest Island (Western Australia) where the animals live in a disturbed habitat under seasonally adverse conditions. In the study reported here *Salmonella* infections and animal condition were examined in mainland and an isolated island population where the animals were believed to be living under more favourable conditions. On the mainland, where the animals do not suffer seasonally adverse conditions, *Salmonella* infections were uncommon. Under the stress of caging, however, the animals became markedly susceptible to infection. On Bald Island, which is remote and little disturbed by human activities, the animals were found to be suffering a summer starvation similar to but not as severe as that seen on Rottnest island. *Salmonella* infections were correspondingly common, with 32% of the animals positive, and included some serotypes typically associated with urban and agricultural ecosystems. Morphometric differences were found between all populations. The results are discussed in terms of the biology of the quokka, and suggest that the Rottnest Island quokka suffered annual starvation before historical records.

Introduction

The cause and significance of *Salmonella* infections in the quokka on Rottnest Island (Western Australia, Fig. 1) have been described by Hart, Bradshaw and Iveson (1985) and Hart, Iveson and Bradshaw (in prep.) These authors found that the Rottnest quokka suffers a dramatic summer proliferation of *Salmonella* infections as a result of the poor quality of forage available to the animals during the hot and dry summer. Although the animals declined seriously in condition during the summer the *Salmonella* infections were not necessarily disease states. The results were interpreted in terms of the degraded state of the Rottnest vegetation and of the usefulness of the *Salmonella* as indicators of adverse conditions. The position of the Rottnest quokka is believed to have deteriorated greatly in recent times due to the influence of human activities which has resulted in gross changes to the vegetation of the island.

In the study reported here these results have been extended by examining other populations of the quokka where the animals were believed to live under more favourable conditions. The quokka was once widely distributed and common in south-western Western Australia but, following an undocumented catastrophe in the early 1930's, it was believed to have become extinct on the mainland and to have survived on only two small off-shore islands (Rottnest Island and Bald Island, Fig. 1). Subsequently it has been found that the quokka persisted over a wide area of its former range and is now regarded as common but in a much reduced habitat. The quokka on the mainland has been studied by Sadleir (1959) and Shield (1964) who concluded that the animals were in better condition than those on Rottnest and did not suffer the summer decline. Almost nothing is known of the Bald Island quokka. The island is remote and rarely visited due to difficult access so that the vegetation has not been disturbed by human activities (Storr 1965). This paper compares *Salmonella* infections and animal condition of a mainland population and the Bald Island population with those of the Rottnest Island quokkas.

Figure 1.—Map showing locations of the study sites.

48860-2

Materials and methods

Study sites

A number of mainland sites known to contain quokkas were examined (Fig. 1) and quokka faeces and other specimens were collected and tested for the presence of *Salmonella*. The population at Holyoake (Fig. 1) was selected for an intensive study. This site is typical of the sites now occupied by the quokka, with extremely dense vegetation around permanent water sources. The site was also inhabited by various feral animals (including rats, mice, cats and pigs) and there was agricultural activity upstream from the site so that the quokkas would have been exposed to exotic serotypes of *Salmonella*.

Bald Island has very difficult access and a single one-night trip was made to the island in February 1980. Quokkas are abundant on the island and occur in all vegetation types (Storr 1965).

Animal trapping

Sadleir (1959) trapped quokkas on the mainland and found them extremely difficult to capture. Using box traps and snares he trapped 13 animals from 1 700 trap-nights over 72 days. In order to improve this, elaborate traps were devised for the mainland study site. The traps were modified from a design devised by officers of the Forests Department (Western Australia) and were baited. A fence was built along a path cleared through the area occupied by quokkas. These paths were 20-50m long. Elaborate falling-door traps opening into small enclosures were built on both sides at the ends of the fence with the doors being released by a trip wire. It is not known whether the baiting was important or whether the animals simply followed the fence in their normal movements. With these traps, extensively pre-baited and re-set several times each night, high trap yields were achieved. In November 1976, 100 trap-nights produced 10 animals (10% yield), and in March 1977, 204 trap-nights produced 27 animals (13.2% yield). For these calculations each fence was regarded as four traps. Box traps were also used in March 1977 but no captures were made from 84 trap-nights.

On Bald Island the animals were caught at night with hand nets and spot-lights.

Sampling, isolation and identification of the Salmonella

Salmonella were sought from soils, waters, faeces and rectal swabs. The samples were treated as described in Hart, Iveson and Bradshaw (in prep.)

Animal condition

The condition of the quokkas was measured in two ways. Firstly the "Condition Index" of Bakker and Main (1980) was used. This is a body weight index related to the "short leg" measurement and was developed from studies on three macropod species, including the quokka on Rottnest Island. The index is applicable only to adult animals, and males and females cannot be compared directly. Secondly the condition of the animals was assessed by subjective judgment of body fat and skeletal muscle.

Results

The mainland

The *Salmonella* found in samples collected from sites on the mainland other than Holyoake are given in Table 1. *Salmonella* infections are uncommon in these animals and their environment.

At Holyoake where quokkas were trapped, held and tested extensively for several days the results were less clear. In November 1976, 10 animals were captured and no *Salmonella* were isolated. Two serotypes (*S. orientalis* and *S. chester*) were recovered from a large number of environmental samples and none from other species caught in the area. In March 1977, 27 quokkas were captured and *Salmonella* isolations were made from 17 of these individuals at some time. However only two serotypes (*S. muenchen* and *S. newington*) were involved and examination of the timing and distribution of infections between the caged animals suggested that the great majority of the infections resulted from cross infection or cross contamination (see Hart 1980). It is likely that all of the infections resulted from original infections in two or possibly three of the animals. Four isolations were made from environmental samples (one each of *S. muenchen, S. give, S. orientalis* and an unidentified *Arizona*) and two isolations were made from individuals of *Rattus rattus* caught in the study area (both of *S. muenchen*).

The mean Condition Index from the two samples of animals from Holyoake were not significantly different (t_{14}=0.55, $p>0.10$ for males and t_{10}=0.053, $p>0.10$ for females) and the two samples were combined. Two adults were caught in both samples and the pooled sample represented 26 adult animals. These values are compared with values from various Rottnest Island

Table 1

Salmonella isolations from mainland sites. Locations are shown on Fig. 1.

Site, date	Species	Sample	No. of samples	Isolations
Byford, 24.ix.76	Quokka	Pools of faeces	1	—
		Pools of faeces	1	*S. orientalis*
		Pools of faeces	1	*S. newbrunswick*
		Pools of faeces	1	—
		Pools of faeces	1	*S. orientalis*
		Pools of faeces	1	*S. orientalis*
Muddy Lake 24.ix.76	Quokka	Faeces	8	—
	Western Grey Kangaroo (*Macropus fuliginosus*)	Faeces	3	—
19.ii.77	—	Soils	4	—
	Quokka	Faeces	4	—
10.iv.77	Quokka	Faeces	12	—
Mowen/Stoats Rds crossing 26.ix.76	Quokka	Faeces	2	—
	Western Grey Kangaroo	Faeces	2	—
Waychinicup Inlet 27.ix.85	Quokka	Faeces	2	—

Table 2

Condition Index (C.I.) values of Holyoake and Bald Island quokkas, compared with those of Rottnest Island populations in the most favourable season (October/November).

1. Holyoake Mean C.I. Variance Sample size	Significance of difference 1-2	2. Rottnest Island Area Mean C.I. Variance Sample size	Significance of difference 2-3	3. Bald Island Mean C.I. Variance Sample size
A. Males				
7.72 1.01 n=16	$t_{25}=3.69$ p<0.01	Settlement 9.17 0.82 n=11	$t_{15}=1.92$ p<0.10	9.93 0.669 n=6
	$t_{31}=1.81$ p<0.10	Non-lake areas 8.31 0.643 n=17	$t_{21}=4.04$ p<0.001	
	$t_{26}=3.68$ p<0.01	Barkers Swamp 9.07 0.650 n=12	$t_{16}=2.00$ p<0.10	
B. Females				
6.89 0.501 n=10	$t_{14}=2.22$ p<0.05	Settlement 7.86 0.84 n=6	$t_{8}=1.36$ p>0.10	8.64 0.325 n=4
	$t_{20}=3.35$ p<0.01	Non-lake areas 8.06 0.687 n=12	$t_{14}=1.17$ p>0.10	
	$t_{22}=1.87$ p<0.10	Barkers Swamp 7.51 0.647 n=14	$T_{16}=2.26$ p<0.05	

Table 3

Condition Index (C.I.) values of Holyoake animals compared with those of Rottnest animals in the least favourable season (April).

Holyoake Mean C.I. Variance Sample size	Rottnest Area Mean C.I. Variance Sample size	Significance of difference
A. Males		
7.72 1.01 n=16	Non-lake areas 6.25 0.86 n=11	$t_{25}=3.7$ p<0.01
	Barkers Swamp 6.92 0.723 n=10	$t_{24}=2.01$ p<0.10
	Bickley Swamp 6.13 1.47 n=7	$t_{21}=3.12$ p<0.01
B. Females		
6.89 0.501 n=10	Non-lake areas 5.65 0.47 n=5	$t_{13}=3.25$ p<0.01
	Barkers Swamp 6.38 0.356 n=11	$t_{19}=1.7$ p<0.20
	Bickley Swamp 5.89 0.99 n=7	$t_{15}=2.27$ p<0.05

populations at the most favourable season in Table 2, and at the least favourable season in Table 3. The Rottnest populations are discussed in Hart, Iveson and Bradshaw (in prep.). The values from the Holyoake animals are intermediate.

Examination of the short leg measurements from the Holyoake animals shows that the Holyoake animals have longer short leg values (Table 4). The short leg values seen with the Holyoake animals are exceptional by comparison with Rottnest animals. For example, in the sample of only 16 adult males the largest value was 137.5mm, while the largest value measured in the study on Rottnest from a sample of several hundred males was 133mm and values of greater than 130mm (slightly above the average at Holyoake) were rare. These results suggest that there is a morphometric difference and that the Condition Index cannot be used for direct comparison.

The assessment of well-being in the Holyoake quokkas was complicated by serious mortality which occurred in the caged animals in March. In the November study there was no mortality of adult animals although some pouch joeys were lost, presumably as the result of stress on the mother. Seven animals died in the March study of which two were frozen for later study. The timing and distribution of animal deaths was not related to the occurrence of *Salmonella* infections (Hart 1980). The two frozen animals were submitted to a veterinarian for post-mortem examination. Neither specimen was suitable for detailed study but both were diagnosed to

Table 4

Short leg (S.L.) values of Holyoake and Bald Island quokkas compared with those of Rottnest Island populations.

1. Holyoake Mean S.L. (mm) Variance Sample size	Significance of difference 1-2	2. Rottnest Island Area Mean S.L. (mm) Variance Sample size	Significance of difference 2-3	3. Bald Island. Mean S.L. (mm) Variance Sample size
A. Males				
129.6 36.76 n=16	$t_{38}=4.6$ p<0.001	Barkers Swamp/Non-lake areas 122.7 9.216 n=24	$t_{28}=3.13$ p<0.01	118.2 9.37 n=6
	$t_{37}=2.1$ p<0.05	Settlement 125.3 35.28 n=23	$t_{27}=2.76$ p<0.02	
B. Females				
118.45 10.97 n=10	$t_{25}=4.0$ p<0.001	Barkers Swamp/Non-lake areas 114.3 3.436 n=17	$t_{19}=4.05$ p<0.001	110.25 0.917 n=4
	$t_{28}=3.56$ p<0.01	Settlement 112.4 21.41 n=20	$t_{22}=0.89$ p>0.10	

have died from haemopericardium. Both were judged to be in poor condition on the basis of reduced skeletal muscle, total absence of body fat, and abnormal cardiac muscle. The first animal had been subjected to a heart puncture, but the second had not. At least the second animal died from haemopericardium resulting from abnormal cardiac muscle and probably induced as the result of stress. Three other animals which died were also examined, and these also had no body fat. Although all animals had possibly reduced skeletal muscle, they were not obviously starved and could best be classified as lean.

Bald Island

The *Salmonella* isolations from 14 quokkas captured on Bald Island and 20 fresh faeces collected off the ground are shown in Table 5. In all, 11 (32%) of the 34 samples were positive. In addition to the serotypes isolated from quokkas, nine isolations were made from water samples (four of *S. charity*, two of *S. typhimurium* and one each of *S. carnac*, *S. bovismorbificans* and *S. saintpaul*). Samples from other species produced three other serotypes (*S. panama*, *S. hindmarsh* and *S. muenchen*).

The Bald Island quokkas were clearly in poor physiological condition, with severely-reduced skeletal muscle. However the Condition Index values were higher than any seen on Rottnest (Table 2). Examining the short leg values in comparison with those of the Rottnest animals (Table 4) shows that the Bald Island animals have short leg values below the normal range seen on Rottnest. It is therefore likely that there is a morphometric difference between the populations, and the Condition Index cannot be used for direct comparison.

Table 5

Salmonella isolations from Bald Island quokkas, 13-14, ii, 1980.

Animal	Sample	Isolations
1.	Duplicate swab	—
2.	Duplicate swab	*S. charity*
3.	Duplicate swab	—
4.	Duplicate swab	*S. bovismorbificans*
5.	Duplicate swab	—
6.	Duplicate swab	—
7.	Duplicate swab	—
8.	Duplicate swab	*S. charity*
9.	Duplicate swab	*S. carnac*; S. 6,8:—:—(O Group C_2)
10.	Duplicate swab	*S. bovismorbificans*
11.	Duplicate swab	—
12.	Duplicate swab	—
13.	Duplicate swab	S. 6,8:—: (O Group C_2)
14.	Duplicate swab	—
15.	Faeces	—
16.	Faeces	—
17.	Faeces	—
18.	Faeces	*S. mersevside*
19.	Faeces	—
20.	Faeces	—
21.	Faeces	*S. typhimurium*
22.	Faeces	
23.	Faeces	—
24.	Faeces	—
25.	Faeces	—
26.	Faeces	*S. carnac*
27.	Faeces	*S. charity*
28.	Faeces	—
29.	Faeces	—
30.	Faeces	—
31.	Faeces	*S. typhimurium*
32.	Faeces	—
33.	Faeces	—
34.	Faeces	—

Discussion

Assessment of the condition of the animals at Holyoake is not clear. Sadleir (1959) found that the mainland animals were in good condition on haematological criteria, and Shield (1964) found that the mainland animals did not show the seasonal anoestrus which is forced on the Rottnest animals by the stressful environment. The results of the present study strongly suggest that the Condition Index cannot be used for direct comparision with the Rottnest animals because of the morphometric difference. Evidence was found that the animals may have an abnormality of the cardiac muscle and a possibly similar condition (myopathy due to vitamin E deficiency) has been described for the Rottnest animals (Kakulas 1961). The almost total absence of body fat in the Holyoake animals is interesting. Rottnest animals have very large fat stores in the most favourable season and Storr (1961) developed a qualitative scale of condition for the Rottnest animals based on fat stores. On this scale the Holyoake animals would be assessed as in poor condition. However, if the Holyoake animals never lay down fat, their lack of fat stores cannot be used as a measure of condition.

The animals at Holyoake were affected by stress in a way which is unknown in Rottnest animals. There is no evidence that this response is important in the normal physiological functioning of the animals and any poor condition was only apparent under the abnormal stress of caging.

Although the Holyoake animals became markedly susceptible to infection under stress, *Salmonella* infections were probably uncommon in wild animals.

On the mainland *Salmonella* isolations from quokkas are uncommon (Table 1). The serotypes present on the mainland include both native and exotic types (see Hart, Iveson and Bradshaw in prep. for a discussion of the serotype groups), and it is likely that the exotic serotypes are widespread but not common in the mainland quokka. *S. newbrunswick*, *S. newington* and *S. give* were the only exotic serotypes isolated from mainland sites. Very intensive searching would reveal further serotypes but the relatively few isolations made at Holyoake despite intensive sampling suggest that the bacteria are present in small numbers and are consequently difficult to detect.

On Bald Island the results were suprisingly similar to those found on Rottnest Island. The animals were in poor condition in summer, although as at Holyoake the morphometric difference prevented the use of the Condition Index. *Salmonella* infections were more common than would be expected for an undisturbed and remote population. Exotic serotypes (*S. bovismorbificans*, *S. hindmarsh*, *S. panama* and *S. typhimurium*) represented a significant part of the serotype range. The Bald Island quokkas suffer some form of gross starvation in summer and this is likely to be due to a summer decline in the nutritive quality of the vegetation as has been described on Rottnest. The climate on Bald Island is essentially similar to that of Rottnest with a long hot summer, however the vegetation of Bald Island has not been subjected to the catastrophic changes seen on Rottnest. The frequency of *Salmonella* isolations suggests that the animals are in a position intermediate between that of the Rottnest animals (where *Salmonella* infections are virtually ubiquitous in summer) and of the mainland animals.

Bald Island has no introduced vertebrates and there has been very little human aetivity, although sheep have been released on the island on at least one oceasion (Hart 1980). Seabirds are the only other possible veetor. These results raise the possibility that the Rottnest quokka experieneed a summer starvation and *Salmonella* proliferation before the effects of European settlement. The proliferation of *Salmonella* on Bald Island would appear to be the result of the susceptibility of the quokka to infection during the summer starvation. Since the vegetation of Bald Island is undisturbed a similar situation was likely to have existed on Rottnest before European settlement. Only native serotypes would have been involved at that time.

Both the Rottnest and Bald Island populations are isolated remnants trapped on islands by the rising sea level at the end of the Pleistoeene and it is possible that they are now surviving in habitats whieh are not favourable to them. The quokka is the only native terrestrial mammal on both of the islands and in the absence of predators it is likely that the populations are eontrolled by food supply in conjunetion with behavioural spaeing meehanisms. Rottnest was isolated from the mainland as recently as 7 000 years ago (Churchill 1959), and Bald Island 10 000 years ago (Storr 1965). From the physieal differences it would appear that these populations have diverged significantly in that time. If both populations have been subjected to regular summer starvation and consequently heavy selection pressure in the absence of predators it is possible that this has been sufficient to cause these changes in the populations.

The presenee of large fat stores in the Rottnest quokka but not the mainland animals suggests that the Rottnest animals have adapted to regular starvation. It is not known if the Bald Island animals lay down fat stores during winter and spring. On Bald Island only four adult females were captured but none of these had pouch young. Four juveniles were eaptured and these were all of a similar age with short leg values at 90-96mm. It is possible that the Bald Island animals have seasonal breeding like the Rottnest animals.

On the mainland the situation is quite different to that seen with the two island populations. Although the animals may not be as well off as previously believed, it is elear that any physiologieal difficulties are not like those of the island populations. Exotic *Salmonella* serotypes are probably widespread in the environment but the quokkas are not readily susceptible to infection, and the *Salmonella* would normally be present in only small numbers.

These results give further support to the proposal by Hart, Bradshaw and Iveson (1985) that the *Salmonella* are useful indieators of stress in wild animals.

Acknowledgements.—The senior author held a Commonwealth Postgraduate Research Award and a research grant from the University of Western Australia during the course of this study. The work at Holyoake was made considerably easier by the generous help of the staff of the Forests Department at Dwellingup, particularly Mr Wally Edgecombe. We also wish to thank Mr Dave Kabay (Department of Fisheries and Wildlife) for collecting samples on Bald Island; Angus Hopkins, Chris Robinson and Ray Smith (Department of Fisheries and Wildlife) for the trip to Bald Island; the Director of Fisheries and Wildlife for permission to work with quokkas on Rottnest and Bald Island; the Conservator of Forests for permission to work at Holyoake; and Dr J. C. McNulty (Commissioner of Public Health and Medical Services) and Dr V. Blackman (Director of the State Health Laboratory Services) for their support in this study.

References

Bakker, H. R. and Main, A. R. (1980). —Condition, body composition and total body water estimation in the quokka, *Setonix brachyurus* (Macropodidae). *Aust. J. Zool.*, **28**: 395-406.

Churchill, D. H. (1959)—Late quaternary eustatic changes in the Swan River District. *J. Roy. Soc. W.A.*, **42**: 53-55.

Hart, R. P. (1980). Ecology of the *Salmonella* in a wild marsupial, the quokka (*Setonix brachyurus*). Unpublished Ph.D. Thesis, University of Western Australia.

Hart, R. P., Bradshaw, S. D. and Iveson, J. B. (1985)—*Salmonella* infections in a marsupial, the quokka (*Setonix brachyurus*), in relation to seasonal changes in condition and environmental stress. *Appl. environ. Microbiol.*, **49**: 1276-1281.

Hart, R. P., Iveson, J. B. and Bradshaw, S. D. (in prep.)—The ecology of *Salmonella* serotypes in a wild marsupial (the quokka, *Setonix brachyurus*) in a disturbed environment.

Kakulas, B. A. (1961). —Myopathy affecting the Rottnest quokka (*Setonix brachyurus*) reversed by α—tocopherol. *Nature*, **191**: 402-403.

Sadleir, R. M. F. S. (1959)—Comparative aspects of the ecology and physiology of Rottnest and Byford populations of the quokka (*Setonix brachyurus* Quoy and Gaimard). Unpublished B.Sc. (Hons.) thesis, University of Western Australia.

Shield, J. W. (1964)—A breeding season difference in two populations of the Australian macropodid marsupial (*Setonix brachyurus*). *J. Mammalogy*, **45**: 616-625.

Storr, G. M. (1961). —Some field aspects of nutrition in the quokka (*Setonix brachyurus*). Unpublished Ph.D. thesis, University of Western Australia.

Storr, G. M. (1965). —Notes on Bald Island and the adjacent mainland. *W. Aust. Nat.*, **9**: 187-196.